Evaluation of Unilateral Vestibular Deficiency and Its Effect on Human Locomotion

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Abstract

The aim of this study is to use the human motion analysis methods to evaluate posture stability status of the patients with vestibular diseases. The most of the posture stability tests are based on comparison of clinical trials realized in two different conditions, i.e. with and without visual information about surrounding environment. Such tests are performed with eyes open, fixed on certain point in front of the subject, and with eyes closed. The acquired results give us opportunity to understand individual diseases of vestibular system in more details. In this pilot research, we studied kinematics of patients with unilateral vestibular deficiency. A group of healthy subjects with simulated unilateral vestibular hypo-function was also analysed to verify our assumptions. The absence of visual information caused reduction of stability, more uncoordinated movements and changes of movement velocities. The velocity of movement responses to maintain posture stability was significantly increased while the walking speed was slowed down. The first results convinced us that the vestibular diseases cause significant orientation errors and that the optical motion analysis methods offer opportunities to recognize and quantify them.

Keywords

Human Posture Stability; Vestibular Deficiency; Human Gait; Motion Analysis

Introduction

Human posture stability depends on combination of various internal and external factors and these are referred to the system of human postural control. Its main role is to counteract the effect of gravity and to maintain postural balance under varying terrestrial conditions. On the other side, unwanted postural sways are very often caused by the diseases of posture control system. However, postural control of human beings relates to the both visual and vestibular input. Therefore, the stability of bipedal posture can be strongly improved by having visual information about surrounding environment. Considering human movements, it is possible to recognize stationary and moving visual information. Stationary visual information has a stabilizing effect on posture, while the effect of moving visual information destabilizes the posture. To maintain well-balanced posture it is necessary to have an ability of continuous stabilization. Such process usually fatigues the human body.

Human motion activities, including locomotion and gait, require also continuous control and stabilization process. To prevent falls and/or unwanted body sways while moving/walking, it is necessary to predict a motion related factors that may vary according to the subjects' surroundings. Also the ability to know an expected quality of intended motion/motions is very important. Then, such feedforward information can be used to stabilize the body posture. Control of human posture depends also on the feedback information from afferent sensory input of visual system, vestibular system as well as somatosensory receptors. The receptors report changes in position and velocity of the body. It is evident that the stability of human posture can be affected by both the internal and the external factors. There are various approaches to study their effects used in the specified laboratories and/or clinical praxis all around the world.

Unilateral Vestibular Deficiency

Unilateral vestibular deficiency presents one of the stability disorders that affect the quality of human life. In that case, the vestibular input plays the significant role. It is because the patients without vestibular input

or with the loss of vestibular functions are not able to perform locomotion tasks in a qualitative better and efficient way. Here, the tasks like standing on one foot or heel/toe walking can be included. Even if the vestibular input may appear as an unessential factor in the control process of quiet standing and/or maintenance of fundamental locomotion balance, we have to oppose this because of patients troubles resulted from the disease influencing, for example their personal and social existence.

Previous studies have also confirmed that in acute stages, after unilateral labyrinthine lesion, the walking trajectories have been deviated to the lesion side as the body sway increased in the frontal plane. To study the gait parameters of persons with unilateral vestibular deficiency it is necessary to consider the status and the functionality of all visual, proprioception and vestibular systems.

Goal directed gait in healthy subjects can be realized without keeping our vision on the target place. Usually, it is enough to see the place, and after visualization (and memorization) one can close his/her eyes and walk directly to the target. Also the patients with bilateral and compensated unilateral vestibular lesions can walk straight ahead without the vision. However, this ability is disturbed in patients with unilateral vestibular lesions. To verify it, the human motion analysis systems can be used as one of the perspective methods for evaluation of human gait in clinical practice. Furthermore, this allows comparison of several independent trials.

Groups of Subjects

Kinematical gait parameters of seven patients with unilateral vestibular disease were analysed in the pilot research study. The group consisted of 3 males and 4 females with ages ranging from 24 to 52 years (mean=36.4, SD=10.3). All these patients were tested in the time from 1 to 3 weeks after recognizing the disease. Other patients who were unable to realize independent locomotion activities were excluded from the study.

Seven healthy subjects without any known vestibular deficiency were also analysed to get normal control data. This group of subjects included 1 male and 6 females with the ages ranging from 23 to 54 years (mean=33.0, SD=12.4). The unilateral vestibular hypo-function of these subjects was induced by irrigation of ear canal with 20ml of tepid water (20°C) during 10s. The left side was irrigated in all of the subjects to have the same conditions. Tests of walking started 20s afterwards.

Methods of Clinical Trials

Both the patients and the healthy subjects underwent two types of tests. First test analysed kinematical parameters and movement trajectories of gait with eyes open. The second one, followed immediately after the first one, analysed gait with eyes closed. The subjects were asked to walk at their natural waking speed along the 8m long path. The efficient distance, when the subjects were asked to turn back (180°), i.e. change the direction of gait, was 5m in both types of tests with eyes open and closed. Particular turns back (in all subjects) were instructed by the clinicians. After reaching the first end point of the path, the subjects turned back to the left side, and then they walked back to the starting point. Then, they turned back again, but to the right side, and walked to the end point again. In that sense, the subjects passed the length of walking path three times. The tests realized in the group of patients are:

- gait with eyes open
- gait with eyes closed

The group of healthy subjects underwent the same set of tests two times. First before stimulation and then after stimulation of ear canal. The tests of healthy subjects were as follows:

- gait with eyes open before stimulation
- gait with eyes closed before stimulation
- gait with eyes open after stimulation
- gait with eyes closed after stimulation

To analyse kinematics of human gait a six cameras optical motion analysis system (SMART, BTS) was used. Subjects were equipped with small „passive markers“, attached to their anatomical landmarks according to the predefined marker set. We specified the set of 17 markers that offered us all the requested information about the motions of the body and its segments related to the process of maintaining well balanced posture while walking. These markers tracked the position and trajectories of forehead, C7, right and left shoulder, right and left wrist, S2, right and left ASIS, right and left femur epicondyle, right and left lateral malleolus, right and left heel, right and left fifth metatarsal head. All these points were captured during the tests by six infrared cameras and their 3D trajectories were automatically reconstructed by the computer. 3D reconstruction was obtained thanks to the synchronization of used infrared cameras.

Motion trajectories were used to get other kinematical parameters. Then, these parameters were analysed to obtain the detailed description of the gait. Here analysed parameters included length of COM trajectory (m), walking speed (m/s), leg speed (m/s), stride length (m), stride time (s), rhythm (strides/minute), step length (m), step time (s), cadence (steps/minute), stance and swing phase (%).

The parameters were analysed individually within the subject and within the groups of here included subjects as well. Except of kinematics, the clinicians also visually monitored the strategies used by the subjects to retain stability and continuity of locomotion. The experimental protocol for the study was approved by a local ethical committee. Subjects were informed about the study and gave clinicians their written consent.

Results

Gait analysis report was used to notify summary of patient's data (including age, sex, diseases etc.) and all obtained results. The subjects were evaluated separately, especially the patients, where it was required due to severity of their disease.

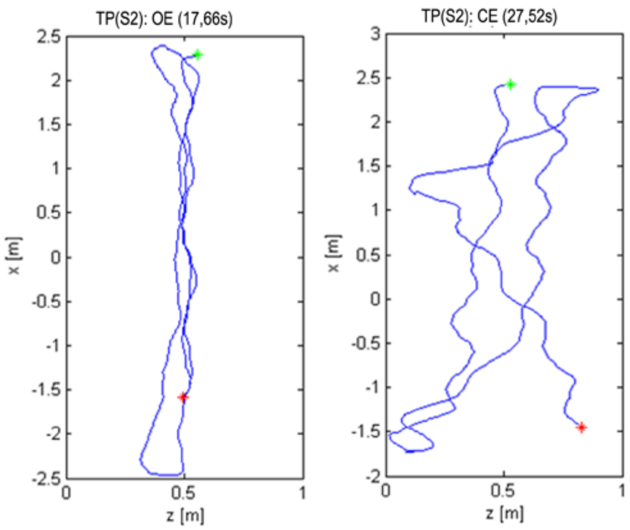

FIG. 1 WALKING TRAJECTORIES OF 43 YEAR OLD MALE PATIENT WITH UNILATERAL VESTIBULAR NEURITIS. WALKING WITH EYES OPEN (LEFT) AND WALKING WITH EYES CLOSED (RIGHT)

Figure 1 shows an example of COM trajectories of one of the patients with unilateral vestibular neuritis during realized walking tests. In this case, the distances passed by the patient were almost the same, 13.88m in test with eyes open and 13.73m in test with eyes closed. However, the duration of test without visual information took longer time for almost 10s, and also the effect of disease is evident as the area to be covered by the patient' gait trajectory was widened from 0.21m to 0.89m.

First of the analysed parameters, walking speed, showed high correlation between the tests with eyes open and eyes closed as well as between the test before and after turning back. Absence of visual information and changes in direction of movement caused significant deceleration of walking speed. The results of patients and healthy subjects are summarized in the table 1.

TABLE 1 WALKING SPEED IN PATIENTS AND HEALTHY SUBJECTS

	P		H		HS	
Test	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
EO1	0.840	0.149	1.017	0.188	1.032	0.135
EC1	0.770	0.150	0.887	0.104	0.824	0.139
EO2	0.864	0.173	1.061	0.181	1.093	0.138
EC2	0.688	0.180	0.789	0.098	0.744	0.159

The shortcuts used in the table 1 are specified as follows: P – patients, H – healthy subjects, HS – healthy subjects after stimulation (simulated unilateral vestibular hypo-function), EO – eyes open, EC – eyes close, 1 – gait before turning back and 2 – gait after turning back.

Deceleration was confirmed in all cases comparing all the realized tests with the eyes open and eyes closed. Statistical analysis was performed to determine whether the change of walking speed was statistically significant or not. In the case of patients, the mean change of walking speed between the gait with eyes closed before turning back and after turning back (M=0.082, SD=0.094, N=7) was significantly greater than zero, and t(6)=2.096, two-tail p=0.090 (95% CL=0.087), provided evidence about the significant deceleration. However, patients gait with eyes open before turning back and after turning back had no significant mean change of walking speed (M=0.024, SD=0.068, N=7), t(6)=-0.498, two-tail p=0.640 (95% CL=0.067).

An impact of visual information absence was recognized also in healthy subjects, where the mean change of walking speed between the gait with eyes open before stimulation and after stimulation (M=-0.015, SD=0.077, N=7) was not significantly greater than zero, with t(6)=0.072, two-tail p=0.945 (95%

CL=0.071). The significant mean change of walking speed (M=0.063, SD=0.126, N=7) was confirmed in gait with eyes closed where t(6)=1.701, two-tail p=0.150 (95% CL=0.117), provided evidence about the significant deceleration.

All of the kinematical parameters, except of length of COM trajectory and walking speed, were analysed separately for each side. Affected side of healthy subject was the left side due to the stimulation, so it was easier to identify potential effect on gait characteristics. Then, the unilateral weakness has been measured for each analysed parameter as the ratio of the difference between two values of parameter at the unaffected and affected side to their sum.

Statistical analysis of kinematical parameters in the group of patients showed that the statistically significant differences, at the significance level of 0.05, within the conditions of eyes open and closed were observed for stride time (M=0.015, SD=0.034, N=7, t(6)=0.9693, two-tail p=0.3769, 95% CL=0.031), rhythm (M=0.015, SD=0.034, N=7, t(6)=0.9693, two-tail p=0.3769, 95% CL=0.031), step length (M=0.019, SD=0.047, N=7, t(6)=1.1354, two-tail p=0.3077, 95% CL=0.043), stance phase (M=-0.002, SD=0.034, N=7, t(6)=0.9277, two-tail p=0.3961, 95% CL=0.031) and the swing phase (M=0.004, SD=0.066, N=7, t(6)=0.8843, two-tail p=0.4170, 95% CL=0.061). Summary of the statistics is listed in the table 2.

TABLE 2 STATISTICAL ANALYSIS OF UNILATERAL WEAKNESS RATIO FOR KINEMATICAL PARAMETERS IN ANALYSED PATIENTS BETWEEN THE CONDITIONS WHEN EYES WERE OPEN AND CLOSED

Parameter	T(6)	Two-tail p
leg speed (m/s)	-0.4947	0.6418
stride length (m)	0.3703	0.7264
stride time (s)	0.9693	0.3769
rhythm (strides/minute),	-0.9695	0.3768
step length (m)	1.1354	0.3077
step time (s)	-0.2461	0.8154
cadence (steps/minute)	0.2462	0.8154
stance phase (%)	-0.9277	0.3961
swing phase (%)	0.8843	0.4170

Similarly, the influence of walk direction change, caused by turning back on the walking path showed that the step length, step time and cadence while walking with eyes open and the stride time, rhythm and step length while walking with eyes closed were significantly changed in the group of analysed patients.

Group of normal data (healthy subjects) provided evidence that the mean change of stride length (M=0.047, SD=0.094, N=7, t(6)=1.2897, two-tail p=0.2536, 95% CL=0.087), stride time (M=0.040, SD=0.071, N=7, t(6)=1.4749, two-tail p=0.2003, 95% CL=0.065), rhythm (M=0.040, SD=0.071, N=7, t(6)=-1.4749, two-tail p=0.2003, 95% CL=0.065), step length (M=0.045, SD=0.071, N=7, t(6)=-1.2981, two-tail p=0.2509, 95% CL=0.066), step time (M=-0.047, SD=0.096, N=7, t(6)=-1.2161, two-tail p=0.2782, 95% CL=0.089), cadence (M=0.047, SD=0.096, N=7, t(6)=1.2163, two-tail p=0.2782, 95% CL=0.089) and swing phase (M=0.002, SD=0.110, N=7, t(6)=0.8161, two-tail p=0.4515, 95% CL=0.102) were significantly different than zero comparing the gait with eyes closed before stimulation and after stimulation (table 3).

TABLE 3 STATISTICAL ANALYSIS OF UNILATERAL WEAKNESS RATIO FOR KINEMATICAL PARAMETERS IN ANALYSED HEALTHY SUBJECTS BETWEEN THE CONDITIONS WHEN WALKED BEFORE AND AFTER STIMULATION WITH EYES CLOSED

Parameter	T(6)	Two-tail p
leg speed (m/s)	0.1261	0.9046
stride length (m)	1.2897	0.2536
stride time (s)	1.4749	0.2003
rhythm (strides/minute),	-1.4749	0.2003
step length (m)	-1.2981	0.2509
step time (s)	-1.2163	0.2782
cadence (steps/minute)	1.2163	0.2782
stance phase (%)	-0.5662	0.5958
swing phase (%)	0.8161	0.4515

The unilateral weakness ratio obtained from all parameters was compared between all tests separately and the changes of their values between individual conditions are highly correlated. Coefficients of unaffected side of patients and healthy subjects are similar. Also the comparison with stimulated side showed high correlation.

Conclusions

Changes of posture, mainly during acute phase of vestibular diseases are important for both the clinical examination and the following treatment procedures. One of the ways to get more information about the maintenance of erected and stable posture is to use the optical motion analysis systems. Using them the clinicians are allowed to reveal which type of balance strategy was used by the patient to maintain stable posture in motion activities.

These techniques helped us to identify small modifications of kinematics. Also the changes of head and trunk orientation towards the lesion side were identified. It was confirmed that vestibular system has an important role in path integration and direction of movements. Degree of navigation impairment, in the case of visual input absence, depends on size of vestibular damage and time elapsed from beginning of the disease. The asymmetrical internal representation of subjective vertical line, due to otolith damage, around which is the body reoriented in space, cause increased turn errors. Deviation of gait trajectory is more obvious after challenging stimulus of body rotations. The study also showed that the unilateral hypo-function seems not to affect the outcome of unaffected side.

Here presented results, together with all the kinematical parameters acquired from patients in acute phase of vestibular neuritis as well as from subjects with stimulation of vestibular hypo-function were significantly more unstable without the visual information. Even if we did not register any falls during the tests, the negative changes in locomotion were in all cases affected by the lesion side.

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